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STUDIES ON QUESTIONS OF DESIGN AND CONSTRUCTION OF
CHAIN SCRAPER CONVEYORS

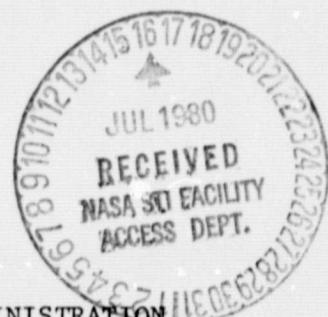
Hubert Guder

(NASA-TM-75810) STUDIES ON QUESTIONS OF
DESIGN AND CONSTRUCTION OF CHAIN SCRAPER
CONVEYORS (National Aeronautics and Space
Administration) 35 p HC A03/MF A01 CSCL 131

N80-26663

Unclassified
G3/37 23600

Translation of "Untersuchungen zu Fragen der Auslegung und
Konstruktion von Kettenkratzerförderern," Glueckauf-forschungshefte,
Vol 3; June 1969, pp 103-116



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

MARCH 1980

STANDARD TITLE PAGE

1. Report No. NASA TM-75810	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle STUDIES ON QUESTIONS OF DESIGN AND CONSTRUCTION OF CHAIN SCRAPER CONVEYORS		5. Report Date March 1980	
7. Author(s) Hubert Guder		6. Performing Organization Code	
9. Performing Organization Name and Address SCITRAN 1482 East Valley Road Santa Barbara, CA 93108		8. Performing Organization Report No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		10. Work Unit No.	
15. Supplementary Notes Translation of "Untersuchungen zu Fragen der Auslegung und Konstruktion von Kettenkratzerforderern," Glueckauf- Forschungshefte, Vol. 30, No. 3, June 1969, pp 103-116		11. Contract or Grant No. NASW-3198	
		13. Type of Report and Period Covered Translation	
		14. Sponsoring Agency Code	
16. Abstract			
17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 35	22. Price

Studies on Questions of Design and Construction of

Chain Scraper Conveyors

Hubert Guder, Aachen¹

The economic success of modern high-performance mining operations presumes a knowledgeable planning of the machines and equipment used. Particular care should be used in the design of the brace conveyors. It turns out that previous methods of calculation of conveyor size, drive power and chain strength are unreliable. In most cases these technical data are determined by rough calculation or empirically. Incorrect decisions can therefore hardly be avoided.

It is the objective of the present studies to clarify the conveyance process in chain scraper conveyors and to determine the resistance forces and characteristics of the conveyor. Previous measurements on chain scraper conveyors [1.2.3]² do give information about the forces in the studied conveyors, but a generalization of the results and transfer of specific values to other operating cases is not possible since important parameters have been ignored or must be estimated.

Principles for Planning Chain Scraper Conveyors

The planning sequence of a chain scraper conveyor is divided into three primary steps:

1. Conveyor size and chain speed
2. Drive power and drive mechanism
3. Chain dimensioning and prestress.

First the conveyor size and chain speed are fixed according to the quantity of conveyed goods and the potential fill cross-sections by using the continuity

¹ Excerpt from the dissertation "Studies on the Conveyance Process, Coefficients of resistance and characteristics of chain scraper conveyors under Consideration of Employment Conditions in Bituminous Coal Mining. Tech. Univ. Aachen 1968. Ed.: Dr. Bernhard Sann, Co-ed.: Dr. Heinrich Koch.

² The numbers in brackets refer to the literature section at the end of the paper.
*Numbers in margins indicate pagination in original foreign text.

equation. The first calculation sequence provides the quantities needed for the second and third planning steps. Chain and power calculation are interdependant since the average static chain load is used as the drive force and the drive mechanism--head drive only, head and tail drive or tail drive only--has an important influence on chain stresses. The unusual chain stresses like blocking of the conveyor, shock stresses of the chain due to the polygon effect of the chain drive and due to dry friction in the troughs are taken into account by safety margins in the static base loads. In the calculation equations we are dealing with physical laws whose application is problematic owing to the uncertain coefficients and efficiencies. Under the presumption of proper distribution of drive forces, the drive powers for the primary drive are:

$$N_{IIa} = \frac{\psi c_u (q_0 + q_k) l \cos \alpha v \pm (q_0 + q_k) H v}{102 \eta_A \eta_K} [\text{kW}] \quad [1]$$

and for the auxiliary drive: $N_{IIb} = \frac{\psi c_u q_K l \cos \alpha v \mp q_K H v}{102 \eta_A \eta_K} [\text{kW}] \dots [2]$

The curviness of the conveyor in the plane of conveyance and perpendicular to this plane can be caused by bending of the troughs and by unevenness of the floor of the seam. Conveyor curves cause a greater power demand which is considered in equations 1 and 2 by the factor ψ . The extent to which the force and power margins can be calculated by the laws of clinging friction [5] will have to be determined by experiment. All other coefficients of the equations will also have to be determined by laboratory and operating tests. Specific studies of the individual quantities are more advantageous than the method of power measurements [1,2]. Individual studies permit the elimination of interfering quantities and ensure a greater reliability regarding operation and construction of the conveyor since the most different parameters can act in a defined manner.

If we ignore the drives, then for the actual conveyor we need to determine the coefficient of resistance of the upper and lower end-piece, the curve factors

³The symbols used are explained at the end of the report.

and the chain drive losses by measurements. The chain drive studies should be performed on a suitable test stand in the laboratory. The test stand should permit simulation of forces occurring in conveyor operation according to their magnitude and effect on the chain gears. The coefficients of resistance of the lower end-piece shall be measured on conveyors in underground pit mining. The low construction height of the conveyors and the open lower end-piece cause resistances--particularly on movable brace conveyors--which cannot be simulated accurately in the test field. Determination of curve factors should be done in the test field. Laboratory tests offer the advantage over operational tests that the geometric shape of the conveyor curves and their distance to the drive mechanism and the conveyor stresses can be more easily and accurately generated and measured. The coefficient of resistance and the characteristics of the conveyor or upper end-piece shall be determined by large-scale tests over several days. W. Ostermann [3] names one of the greatest difficulties in conveyor measurements in underground pit mining as the detection of conveyor load. In the test field this is less problematic since the conveyed goods can be weighed. Measurements of the coefficient of resistance as a function of the characteristic quantities of the crushed goods is hardly possible in underground pit mining.

Test Stand for Determination of Coefficient of Resistance and Characteristics of the Conveyor End-piece

The coefficient of resistance can be determined in normally operating conveyors with endless chain by two measurement methods. In one method the conveyor is equipped with head and tail drive. The chain gear input torques are measured at both drives. To calculate the end-piece resistance the chain drive losses must be known. The method has the following disadvantages:

1. High cost and large space requirement for a circular conveyance
2. The load cannot be kept constant over the entire conveyor length for a uniform load on the test conveyor
3. The particular load weight on the conveyor can be roughly determined during the test
4. The chain prestress is unknown
5. The chain gear losses must be known for the particular load range.

Another method is direct measurement of the forces in the circulating chain. Measurement of chain forces in the upper end-piece and lower end-piece is quite difficult and requires a wireless transfer of measured values in addition to special transducers. The disadvantages numbered 1-3 above also occur here.

The problem thus arose of developing a test stand which did not have the disadvantages and difficulties mentioned above. Besides the coefficients of resistance for a certain speed, the characteristic profile of the conveyor end-piece would have to be picked up by the test stand. In the analysis of the conveyor process there is one method which meets all requirements and does not have the disadvantages outlined above. If we consider a section of the conveyor flow at any point of the upper end-piece then it is of no importance to forward motion of the goods and the occurring resistances how the needed drive force is fed to the chain. The drive of the endless circulating chain by chain-wheels at the conveyor ends is needed to maintain a constant conveyance. For test purposes we can ignore the circulating tension medium. A continuous chain of defined length loaded with goods can be drawn through the trough loop.

The test conveyor was 40 m long (fig. 1) and consisted of conveyor troughs PFI of Eisenhuette Works Westfalia, Altluenen. A double-chain belt with an effective length I_R provided with scrapers at 1 m separation could be pulled through the measurement range I_N . The conveyor was equipped with 500 mm tall, perpendicular sheet-metal pieces on both sides. Limitation of the load section I_B occurred through valves which are supported against the neighboring tang.

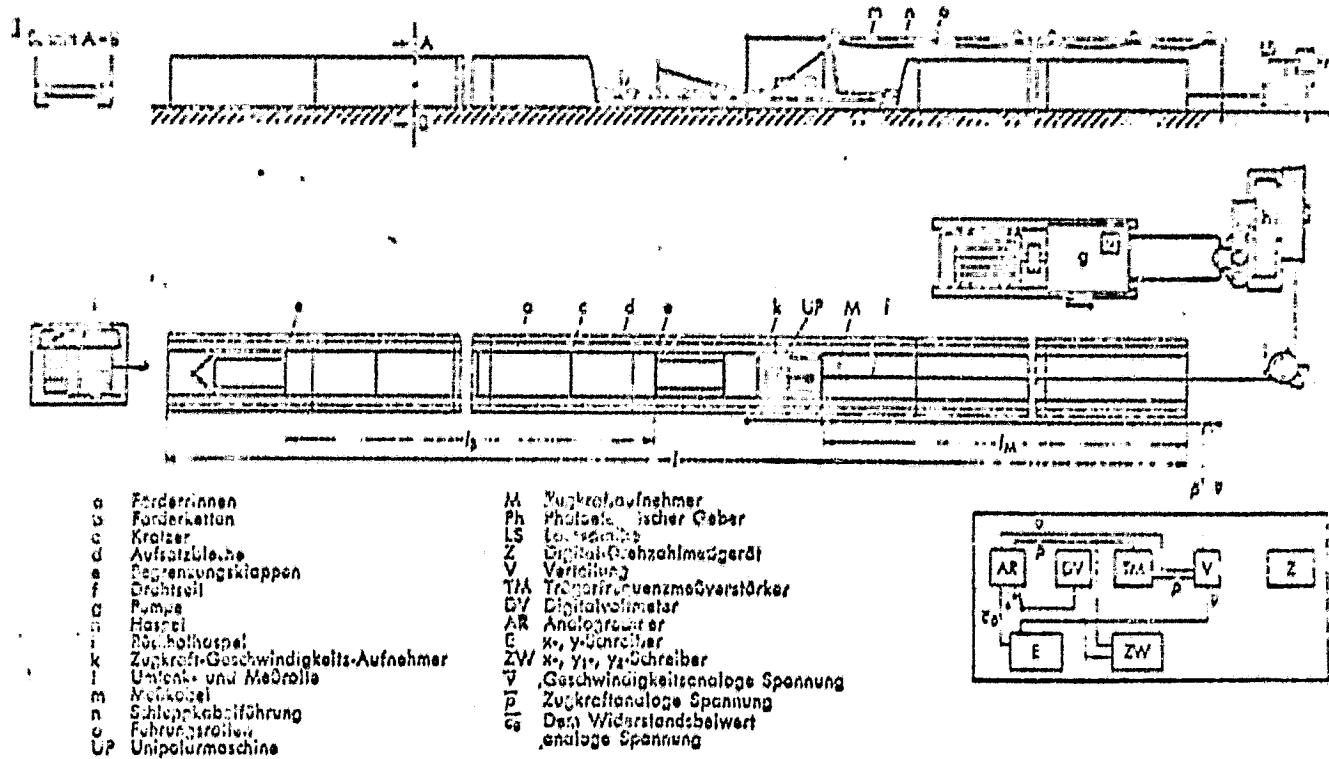


Figure 1. Schematic Representation of the Test Stand

Key: 1-section A-B α -conveyor troughs; b-conveyor chain; c-scraper d-sheet-metal pieces; e-limit valves; f-suspension cable; g-pump; h-winch; i-retention winch k-tensile force/speed transducer; l-diversion and measurement roller; m-measurement cable; n-drag cable lead; O-feed rollers; UP-homopolar generator; M-tensile force transducer; Ph-photoelectric transmitter; LS-perforated disc Z-digital RPM unit; V-distribution; TM-carrier frequency measurement amplifier DV-digital voltmeter; AR-analog computer; E-x,y-printer; ZW-x, y_1 , y_2 -printer \bar{V} -analog speed voltage; \bar{P} -analog tensile force voltage \bar{C}_o -voltage analog to coefficient of resistance.

The test chain loaded with conveyance goods was drawn through the measurement range by a suspension cable by a continuously-adjustable winch. The chain force and speed were measured. The tests were reproducible. A rearward located winch moved chain and test goods back to the initial position. To record the characteristic lines during acceleration of the test chain from zero speed to terminal speed a tensile-force/speed transduce and an analog computer were developed and used.

Test Results

The Test Project

The coefficients of resistance in the chain scraper conveyors are generally unknown. In general we calculate for upper and lower end-piece with a friction

coefficient of 0.35 [4, 6]. Indications on the dependance of the coefficients of friction on the properties of the conveyed goods like moisture content, lumpiness etc. are given by A.O. Spiwakowski [7] without details. He recommends calculation with 0.4 to 0.8 for coal. W. Ostermann [3] and W. Siegl [8] report on the influence of moisture on the end-piece resistance.

According to results of extensive preliminary tests and under consideration of the physical properties of coarse coals in German coal mining [9] the following test parameters were found: Quality of granular structure, moisture, density and mine content of tailings. Other parameters considered were: conveyor idle, size of conveyor load, down times of loaded conveyor and conveyor construction type. More accurate information on the conveyance process is only possible if the actual friction between goods and trough is known. The effective friction in the conveyor was measured in special test apparatus.

The resistances in chain scraper conveyors are composed of sliding friction coefficients at the trough base and at the side borders and of additional resistances caused by circulation and grinding of the goods. Pure sliding friction is present for conveyor idle and when the goods are moved forward without relative motions and without grinding. For the coefficient of resistance we can write in generalized form:

$$c_0 = \mu + k_1 + k_2 \dots \dots \dots \quad [3]$$

In the equation μ is the sliding friction coefficient of the chain and the load in the trough loop. It is designated as a mixed frictional coefficient since it contains the friction value between chain and trough and the friction value between goods and trough. The value k_1 is a factor containing the sum of additional resistances; k_2 should contain the wall friction coefficients which will be discussed below.

Friction Characteristics of Conveyor Idle

The resistances of the idle conveyor end-piece depend greatly on the trough

condition and can increase by about 100% over smooth troughs due to impurities in the conveyor from dirt. The idle characteristic field of the chain conveyor can be divided into three regions (fig. 2). In region 'a' the idle resistances of new conveyors move with greatly oxydized troughs and chains. Likewise, in this region chain conveyors in quarry operations are classified, but with even greater resistances for idle operation. The characteristic band of region b results for idle tests after test stand shut down from 5 to 10 days. We should

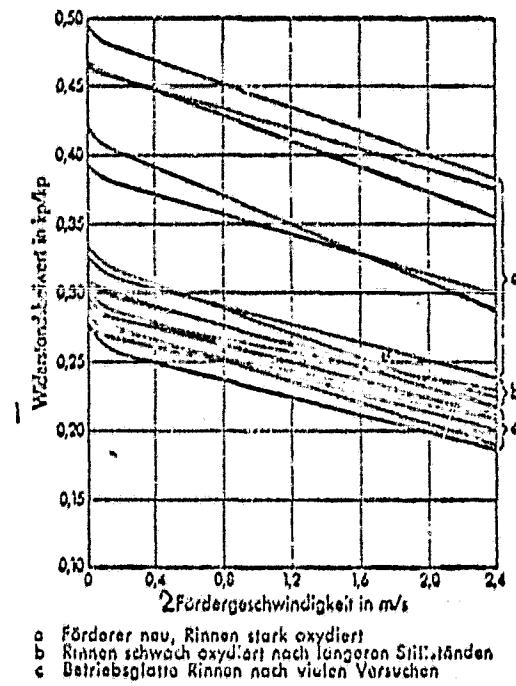


Fig. 2 Idle Characteristics of the Conveyor End-Piece

Key 1-coefficient of resistance in kp/kp; a-new conveyor, troughs greatly oxydized b-troughs weakly oxydized after longer shut down c-smooth troughs after many tests 2-conveyance rate in m/s

mention here that the trough oxidation can be generally prevented by warm-air heating in the test shed. In underground pit mining greater oxidation layers can form on the conveyor due to shut-down times at weekends, depending on pit climate. For normal operation of a brace conveyor the idle characteristics of region c are important. The conveyor end-piece is run in this state through a longer operation of "blank-steel" and "rough wear."

The average value characteristic of region c deviates by about $\pm 5\%$ from $/10$, the limit values. Errors of $\pm 10\%$ occur for a joint average value characteristic for regions b and c. K. Ehrlenspiel [10] and F. Gartner [11] consider test dispersions of $\pm 10\%$ unavoidable for experiments with solids friction (these authors are studying questions of smooth friction recently). In the studies care was taken that the idle or start characteristics of more important comparison test series lay within the narrow stray region c of the normal conveyance operation.

The Dependence of the Coefficient of Resistance on Granular Structure of the Goods

The influence of granular structure on the size of the coefficient of friction was explained first in order to determine to what extent this factor had to be taken into account in the other tests. The goods in coal mining have a broad granular fluctuation with sizes $< 0.5\text{mm}$ up to pieces of several decimeters edge length. The granular shape varies widely and fluctuates between the shape of a sphere and a polyhedron. For the tests commercially available nut coal and fine coal proved suitable. In order to exclude other influences care was taken to use the same water content and density in the individual test goods. The characteristic line for coarse coal is compared with the resistance characteristics of nut coal and fine coal (fig. 3). The coefficients of resistance for nut coal lie on the average about 35% above the resistance figures for fine and crude coal. The reason for this is found in the conveyance process, in the type of force transfer from circulating tension-means to the conveyed goods, and in the granular structure of the goods. The shear effect of the scraper maintains the conveyor movement. Within the scraper area a basis forms which can also be called the conveyed goods mat. Goods extending above the basis is moved forward by friction contact. In the basis, pressure stresses are acting--these are illustrated in ideal form in fig. 4. A body of goods with sphere-like granules behaves more unstable under the action of the shear forces than a body with cube, plate and jagged-shaped granules. The first goods have

lower internal friction than the latter. The effect of the pressure varies in both types of goods and is denoted as follows: The spherical-like nut coal usually moves pointwise. Thus stress peaks can build up in the zone of larger pressure stresses near the scraper. Torsional and pitching moments can form which induce position changes for individual granules within the body and crush upward parts of the goods from the basis. Constant roll and lift movements in the goods should be watched. These motions cause the larger resistance forces in connection with a goods crushing. In the fine goods however, a uniform pressure distribution is assumed. The fine goods behave like a uniform flow. Relative goods motions seldom occur in the body of goods. The coefficients of resistance of the crude coal exceed those of fine coal only slightly. This might be attributable to a uniform pressure distribution within the basis. The gap volume of the goods is low owing to a large fraction of fine goods; larger goods blocks lie embedded in the fine goods. Here we find conditions similar to fine coal conveyance. In general it was found that the coefficients of resistance of crushed goods with spherical-like granules and narrow range of granular sizes are greater than for fine goods with a broad granular range and high percentage of fine grains.

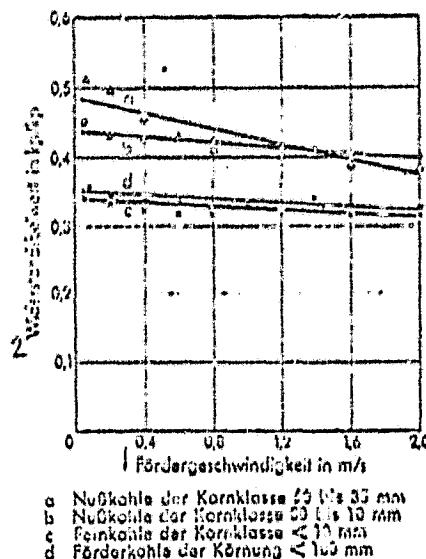
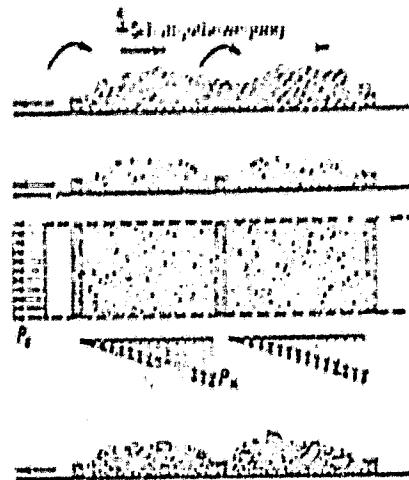


Figure 3. Coefficient of Resistance as a Function of Conveyance Rate for Air Dry Goods having different Granular Structure

Key: 1 rate of conveyance in m/s 2-coefficient of resistance in kp/kp; a-nut coal gran, size 50-35mm b-30 to 10mm c-fine coal size <10mm d- crude coal <100 mm



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Fig. 4 The behavior of goods on the chain scraper conveyor as a function of granular structure.

Top: GoodS7cubic to spherical grains, narrow range (nut coal 50-35mm; 30-10mm)
 Center: Goods fine grain (fine coal <10mm) P_x, P_z pressure distribution in
 the goods (pulverized) within the basis
 Bottom: Goods of broad granular range, coarse grains embedded in fine grains
 (Conveyed coal <100 mm)

Key: 1-Movement of conveyed goods

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The Dependence of the Coefficient of Resistance on Water Content of Conveyed Goods

It was found that fine coal on the chain scraper conveyor behaves like a uniform flow. Additional resistances due to relative goods motions and crushing are generally retarded. The fine coal thus appeared suitable for studies on the influence of the water content on the coefficient of resistance. Figure 5 shows the test results. At a water content of 3.9 % by weight the characteristic line has the profile decreasing with the conveyance speed. The line for 8.9% by weight water is somewhat deeper but runs parallel to the initial line. If the water content exceeds the limit of about 9 to 10% by weight, then the lines rise above the speed. In the range of lower speeds the coefficient of resistance decreases with increasing water content. For the

velocity range used a relative max. resistance value is found at a water content of 14 to 16% by weight; this is shifted in the direction of greater water content at speeds greater than 2 m/s. The increase in characteristic lines above the conveyance speed at water contents >10% shows that the effect of solids friction recedes in favor of flow friction; this effect is greater the higher the water content. This is attributable to the type of water bonding in the goods and to the known processes when passing from solids friction over mixed friction to the region of pure flow-friction.

The bonding of the water in the goods occurs by capillary action and surface forces. The initially low water quantities are initially absorbed by the finest particles. Granular collections adhering together due to the capillary water is surrounded by a water film which comes into being through adsorptive and adhesive effects. Larger granules have no surface water if water content is insufficient. The goods have a lubricated appearance. A complete localization of the water film to the outside surfaces of the goods does not occur until complete saturation of the pore volume with water. The surface water of the moist goods has the same effect as the hydrostatic lubrication of roller bearings. The friction-reducing lubricating film is already present when starting up the conveyer. The characteristic field of fig. 5 shows an analogy to the Stribeck friction curves [16]. The characteristic lines for larger moisture contents intersect the line of the solid or mixed friction range at a point which shifts in the direction of greater speeds as a function of moisture. The curve profile provides proof that at higher water contents a transition from mixed friction to flow friction takes place.

The Dependence of the Coefficient of Resistance on the Type of Goods

The density proved suitable for a presentation of the coefficient of friction as a function of goods types for a clear physical description of the goods.

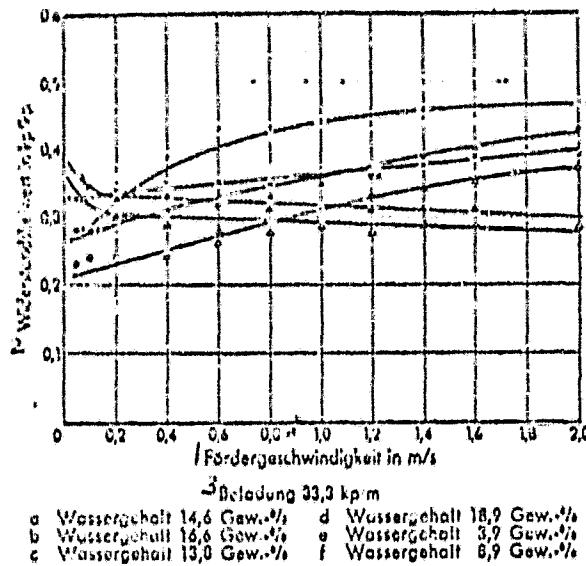


Figure 5. Coefficient of resistance as a function of conveyance speed for fine coal <10 mm for various water contents.

Key 1-conveyance speed in m/s 2-coefficient of resistance in kp/kp 3-load: 33.3 kp/m

a-water content 14.6% (weight) b-water content 16.6% c-water content 13.8%
d-water content 18.9% e-water content 3.9% f-water content 8.9%

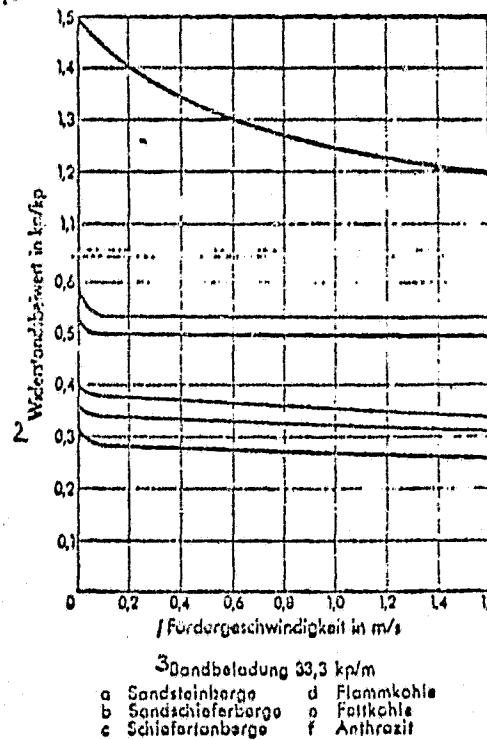


Figure 6 Coefficient of friction as a function of conveyance speed for various types of goods. Key: 1-conveyance speed in m/s 2-coefficient of friction in kp/kp; 3-belt load 33.3 kp/m; a-sandstone tailings; b-sandy shale tailings c-shaly clay tailings; d-flame coal; e-soft coal; f-anthracite

As conveyed goods we used flame coal, soft coal and anthracite and the associated strata of sandstone, sandy shale and shaly clay. The characteristic lines (fig. 6) originate through average-value formation from 4 sequential lines for each type. For coal there resulted a very good relative measurement accuracy. /108 The repeatedly measured lines coincided or had only slight deviations. However, for the hard rocks dispersions of $\pm 10\text{-}30\%$ occurred.

Difficulties were caused by the density test of the goods since there is no density test method generally in use for coal. The known materials' test procedures are generally unsuitable since the coal does not exhibit a uniform density behavior due to its structure. Therefore the hardness test used in the Soviet Union by N M. Protod'jakonow [17] was applied. Figure 7 shows the average coefficients of resistance of the goods as a function of the determined density properties (dust quantity with granular size $< 0.5\text{mm}$). The measured values are compared with the average idle friction values and the calculated coefficients of resistance. The latter are calculated as mixed friction values from the idle and goods resistances by using eq. (4):

$$c_o = \frac{q_K \mu'_K + q_0 \mu'_0}{q_K + q_0} \dots \dots \dots \quad [4]$$

The coefficient of resistance increases quickly for hard rocks. The average coefficient of resistance for sandstone is 152% above the average idle value and 188% above the calculated coefficient of resistance. The relatively low density of coal thus hardly has a measurable effect on resistances in the conveyor.

The goods crushing doubtless occurring here could not be measured.

The Dependence of the Coefficient of Resistance on Tailings Content in the Raw Coal

The ash content of the raw coal used (see fig. 3) was 36.5% by weight. This coal was mixed with 30% shale clay tailings for one test series and with 30% sandstone tailings for another. The coefficients of resistance increased in both cases only slightly, as expected. The behavior of raw coal with a higher tailings content can only be indicated since even for a mixture of coal and rock

it is primarily the coal which causes the conveyance resistance. Due to the large fraction of finest-grain coal in the raw ore, moist coal dust becomes very thick and is deposited like a lubricating film on the larger grains. This fraction of the goods slides easier and less of it gets into the grasp regions of the scraper and chain.

The Dependence of the Coefficient of Resistance on the Conveyor Load

The previous studies were performed with a load corresponding to a fill cross-section nearly equal to the free profile cross-section of the upper end-piece. The goods cross-section of the conveyor is significantly greater in most cases. If the load becomes so large that the goods must be supported by the sheet-metal plates, then the friction against these plates must be added in. The influence of the load was studied for two load levels (fig. 8).

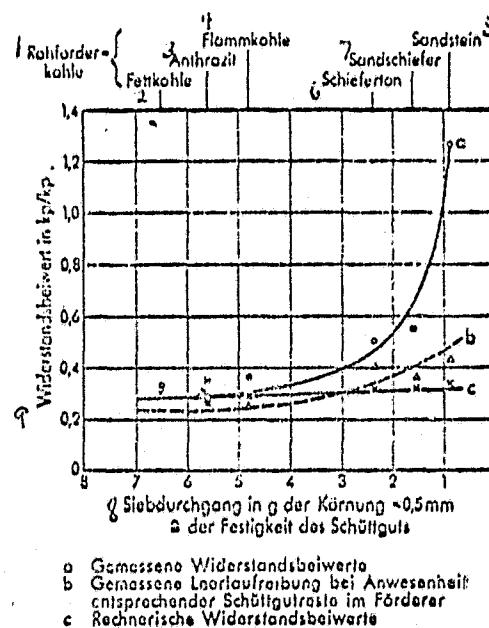


Fig. 7: Coefficient of resistance as a function of goods type expressed according to the density properties according to M.M. Protod'jakonow [17].

Key: 1-raw coal 2-soft coal 3-anthracite 4-flame coal 5-sandstone 6-shaly clay
 7-sandy shale 8-sieve passage in g of grain size $< 0.5\text{mm}$ $\hat{=}$ density of goods
 9-coefficient of resistance in kp/kp a-measured coefficients of resistance
 b-measured idle friction for presence of appropriate goods residue in conveyor
 c-calculated coefficients of resistance

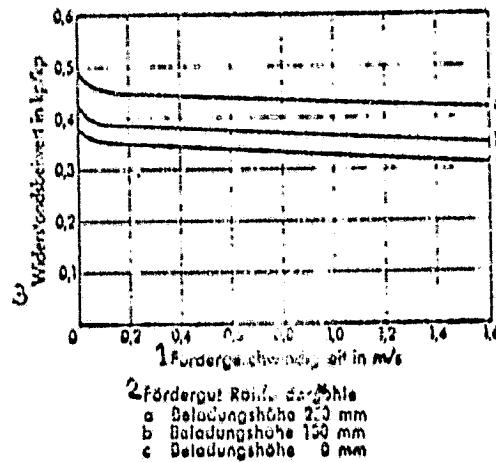


Figure 8. Coefficient of Resistance as a function of conveyor speed for various load levels in the test conveyor.

Key: 1-conveyor speed in m/s 2-conveyed goods: raw coal 3-coefficient of resistance in kp/kp. a-load level 250mm b-load level 130mm c-load level 0 mm.

The Specific Break-loose Force as a Function of Stop Time of the Conveyor

The start-up of the chain scraper conveyor can be greatly impeded by overloads, blocked chain or longer stop times. Start-up of loaded conveyors after longer stop times was simulated in the test conveyor. The loaded chain-belt (load standing level 250 mm) was started up after/a certain time in the initial position.

The illustration of break-loose lines in one thrust was only possible with the tensile force-speed transducer and analog computer since a specific start-up state could not be generated again after initial break-loose.

Figure 9 shows the characteristic lines. The break-loose force increases /109 with the conveyor stop time. The start-up lines drop off sharply with the speed which indicates that we are dealing with large start-up force and genuine break-loose processes. In conveyer operation the chain would accordingly reach normal operating load after one revolution. The results indicate that brief stop times only slightly affect start-up. Longer stops however, can lead to significant start-up difficulties. For a stop time of 68 h the needed start-up force exceeds the normal start-up force by 72%. The increase in break-loose force

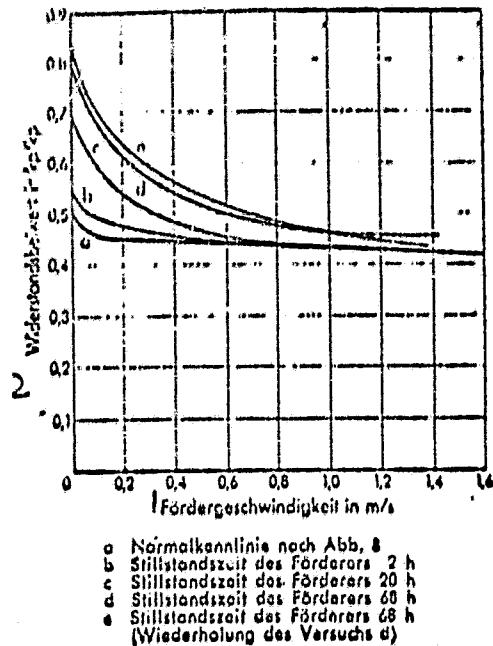


Figure 9. Start-up characteristic lines for the test conveyor for moving raw coal with a load level of 250 mm and different stop times.

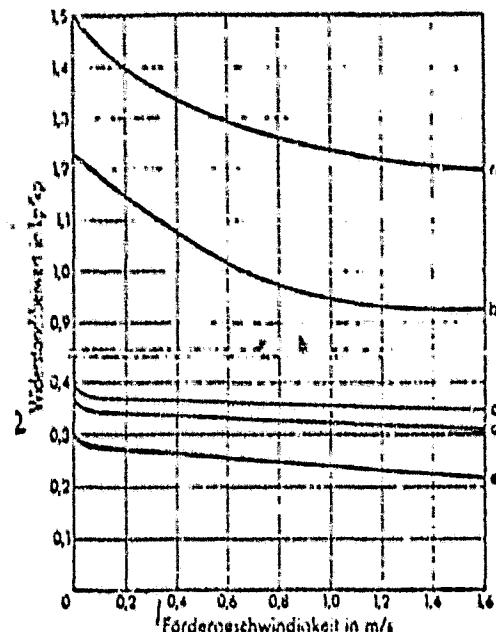
Key: 1-conveyor speed in m/s 2-coefficients of resistance in kp/kp a-normal line from fig. 8. b-stop time: 2h c-stop time: 20 h d-stop time: 68 h e-stop time 68 h (repeat of test d).

with increasing stop times is probably attributable to time-dependant chemical reactions between goods and trough and to fine goods baking on to the chain guides. In contrast to open troughs, troughs covered with goods exhibit a clear rust deposit and traces of backed fine goods after longer exposure time. Briquetting processes in the chain guides are also possible.

Coefficients of Resistance and Characteristic Lines as a Function of Conveyor Construction

After performing the tests with a special conveyor design, the question arises of how much the results are applicable to other conveyor constructions. For a series of comparison tests we used the single-chain conveyor EKF 2 of Halbach & Braun Co., Wuppertal-Barmen. The other equipment of the test system like drive and measurement equipment was not changed.

After longer running-in tests by pulling the loaded chain back and forth, the idle line was taken for smooth trough loop. For the run-in single-chain conveyor this lay in zone c of the idle characteristic field (see fig. 2).



3 Beladungsgewicht 33,3 kp/m bei allen Versuchen
 a Zweikettenförderer mit Sandsteinbergen
 b Einkettenförderer mit Sandsteinbergen
 c Einkettenförderer mit Rehförderkohle
 d Zweikettenförderer mit Rohförderkohle
 e Ein- und Zweikettenförderer im Leerlauf

Figure 10. Coefficient of resistance as a function of conveyor speed for various conveyed goods on single and double-chain conveyors.

Key: 1-conveyor speed in m/s 2-coefficient of resistance in kp/kp 3-load weight 33.3 kp/m for all tests. a-double-chain conveyor with sandstone tailings b-single-chain conveyor with sandstone tailings c-single chain conveyor with raw coal d-double-chain conveyor with raw coal e-single and double-chain conveyors at idle.

Also, the characteristic lines for raw coal (fig. 10) deviate only a little for the two conveyors. The deviation lies within the unavoidable error range. in the single-chain conveyor The coefficients of resistance for sandstone tailings/lie on the average 20% below the comparable values of the double-chain conveyor.

The study results shall be explained with a view toward generalization. With the exception of the results for crushed goods of high density, all other test results are generally valid for chain scraper conveyors with a similar design and comparable construction dimensions. Thus if the conveyance process is subjected primarily to the laws of sliding friction, then the construction of the conveyor has no influence on the size of the resistance coefficients. The differences in the size of these coefficients for sandstone tailings are attributable to the conveyor construction. The goods grinding

occurs primarily between parts of the revolving tension agent and the troughs.

The grinding effect of the chain can be reduced by noting the following construction requirements:

1. The open cross-section between conveyor profile and the scraper cross-section should be as small as possible. According to the cross-section drawings of the studied conveyor constructions, the open cross-section between the scrapers and the trough profile is smaller in the single-chain conveyor than in the double-chain type. The goods grinding is thus greater in the double-chain conveyor due to the drawing of goods particles into the open crevices than in the single-chain type. Where the optimum of cross-section filling of the conveyor profile by the scraper lies, is to be determined by the engineer. To maintain the advantage of spacial flexibility of the trough connections the tolerances should not be reduced down to the dimensions of clearance fits. /110
2. The conveyor chains should be located outside the force feed. Meeting the first condition requires a lengthening of the chain from the force feed. Without this however, we observed in our studies of the double-chain conveyor that pieces of goods were stuck on the chain links running under the flat trough flanges. These could act like brake wedges if their size is large enough.
3. The scraper should not have any sharply bent edges. All construction parts of the tension medium should have no angles promoting grinding.

Characteristic Resistance Lines of Brace Conveyors

Theoretical Background

The study results for low conveyor loads can be applied to daylight conveyance operations depending on the particular crushed goods and the conveyor profile. However, the results for the various conveyor loads apply only to the test conveyor with its rectangular fill cross-section. Fill cross-section shape

and size deviate for brace conveyors from that of the test operation. Larger conveyor loads are supported by the sheet-metal guides and cause additional friction forces. The effective wall pressures can be calculated by using the Coulomb earth-pressure theory [19]. For fluids the wall pressure corresponds to the inherent load of the liquid column lying above. For crushed goods the internal friction reduces the wall pressures. Under consideration of the lateral friction forces we have a general expression for the coefficient of resistance:

$$c_n = \frac{q_K \mu_K + q_H \mu_H + \lambda_n h^2 \gamma \mu'}{q_K + q_H} \quad \dots \quad [5]$$

The measured coefficients of resistance (fig. 8) are compared to the calculated coefficients according to eq. 5 as a function of the load level (fig. 11).

The measured and calculated function profile agree well. The measured coefficients of resistance lie on the average only 7% above the calculated values.

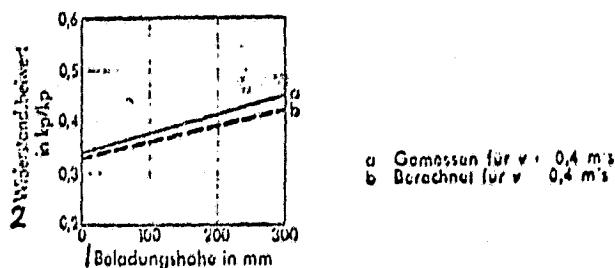
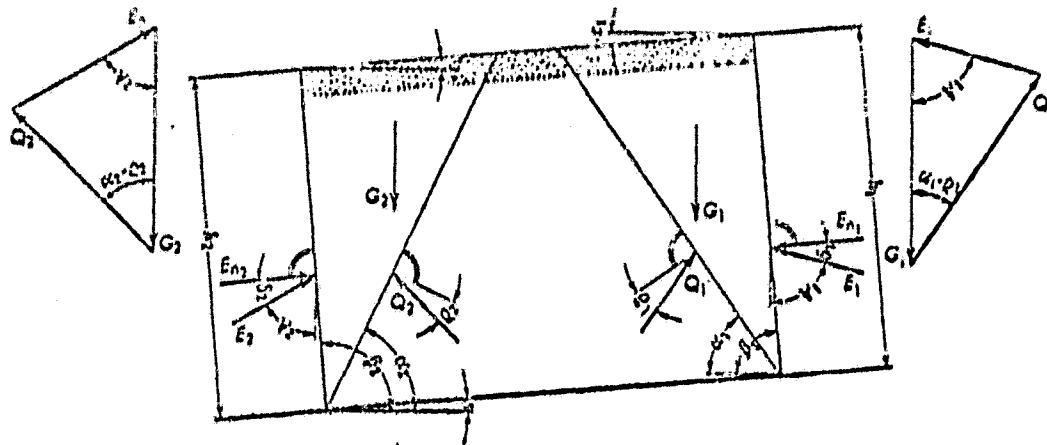


Figure 11. Coefficient of Resistance as a function of the load level for raw coal conveyance.

Key: 1-load level in mm 2-coefficient of resistance in kp/kp a-measured for $v = 0.4 \text{ m/s}$ b-calculated for $v = 0.4 \text{ m/s}$

Application of the Coulomb earth-pressure theory presumes flat sliding surfaces, plumb support walls and horizontal crushed goods surfaces; conditions which can only be realized in the test conveyor. The generalized Coulomb earth pressure theory [19] does permit a calculation of the wall pressures of variable inclines of support walls and of the crushed goods surfaces. Taking fig. 12 as a basis there results the following general equations for normal forces acting on the support walls of a conveyor with variable cross-inclination:



G_1, G_2 Eigengewicht eines Schüttgutkeils
 E_1, E_2 Erddruckkraft 1, 2
 ψ_1, ψ_2 Neigungswinkel der Erddruckkraft 3
 α_1, α_2 Gleitflächenwinkel 4
 α_3, α_4 Reibungswinkel 5

β_1, β_2 Wandneigungswinkel 6
 δ_1, δ_2 Richtungswinkel 7
 E_{1y}, E_{2y} Waagerechte Komponente der Erddruckkraft 8
 α_1, α_2 Neigungswinkel der Schüttgutoberfläche 9
 ψ Neigungswinkel des Förderers 10

Figure 12. Generalization of the Coulomb Theory

Key: 1-eigen weight of a crushed goods wedge 2-earth pressure force 3-incline angle of earth pressure force to the perpendicular 4-sliding surface angle 5-friction angle 6-wall incline angle 7-direction angles 8-horizontal components of earth pressure force 9-incline angles of crushed goods surface 10-incline angles of the conveyor

$$E_{u1} = G_1 \frac{\sin(\alpha_1 - \delta_1)}{\sin(\alpha_1 - \delta_1 + \psi_1)} \cos \beta_1 \quad \dots \quad [6]$$

$$E_{u2} = G_2 \frac{\sin(\alpha_2 - \delta_2)}{\sin(\alpha_2 - \delta_2 + \psi_2)} \cos \beta_2 \quad \dots \quad [7]$$

$$E_{u1} = \lambda_{u1} \frac{h^2 \gamma}{2} \cos \delta_1 \quad \dots \quad [8]$$

$$E_{u2} = \lambda_{u2} \frac{h^2 \gamma}{2} \cos \delta_2 \quad \dots \quad [9]$$

For the pressure factors λ_u of both support walls we have:

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$$\lambda_{u1} = \left[\frac{\sin(\beta_1 - \delta_1)}{\sqrt{\sin(\beta_1 + \delta_1) + \sqrt{\frac{\sin(\delta_1 + \psi_1) \sin(\psi_1 - \alpha_1)}{\sin(\beta_1 - \alpha_1)}}}} \right]^2 \quad [10]$$

$$\lambda_{u2} = \left[\frac{\sin(\beta_2 - \delta_2)}{\sqrt{\sin(\beta_2 + \delta_2) + \sqrt{\frac{\sin(\delta_2 + \psi_2) \sin(\psi_2 - \alpha_2)}{\sin(\beta_2 - \alpha_2)}}}} \right]^2 \quad [11]$$

The function profile of the determined friction and resistance lines has the form given in fig. 13 and can be written in general terms by using the equation:

$$\mu = (\mu_0 - a) e^{-b v} + a - d v \quad \dots \quad [12]$$

The exponential term of eq. 12 goes to zero for the normal characteristic lines (lines for raw coal conveyance) even at a speed of about 0.1 m/s.

For speeds > 0.1 m/s we can use eq. 13 for practical cases:

$$\mu = a - dv \quad \dots \dots \dots \quad [13]$$

General characteristic-line equation for the upper conveyor end-piece is:

$$c_0 = \frac{q_K/\mu_K + q_{11}/\mu_{11} + \left(-\frac{h_1^2}{2} \lambda_{u1} + \frac{h_2^2}{2} \lambda_{u2} \right) \mu_{11} v}{q_K + q_{11}} \quad [14]$$

For the smooth operating conveyor we have:

$$\mu_K = 0.28 - 0.0375 v \quad \dots \dots \dots \quad [15]$$

The friction equation for coal on smooth-running trough is:

$$\mu_{11} = 0.39 - 0.00625 v \quad \dots \dots \dots \quad [16]$$

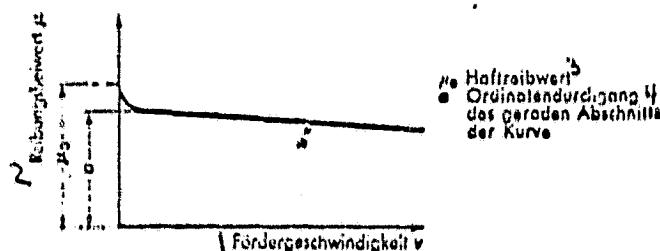


Fig. 13: General function Profile of the Friction and Resistance Coefficients
 Key: 1-rate of conveyance v 2-coefficient of friction μ 3-adhesion friction value
 4-ordinate passage of the straight section of the curve

Equations Dependant on Fill Cross-section

The fill cross-sections of brace conveyors are dependant on the design of the conveyor and location of use--under the presumption of a sufficient conveyor flow. The theoretically possible goods cross-sections are shown by fig. 14. The fill cross-section shapes of fig. 14a and 14b pertain to chain scraper conveyors which are used as intermediate conveyors or in tunnel driving. The fill cross-section shapes occurring in operation differ only slightly from the theoretical shapes. With brace conveyors the situation is different. The actual fill cross-section shapes and sizes (fig. 15) differ significantly from the theoretical cross-sections.(fig. 14c). Extensive fill cross-section measurements on brace conveyors [22] led to the recognition that the effective cross-section shape and size are dependant on the granular structure, the seam thick-

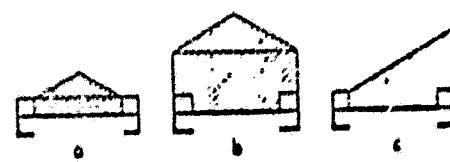


Fig. 14: Theoretical Fill Cross-Section Shapes for Chain Scraper Conveyors

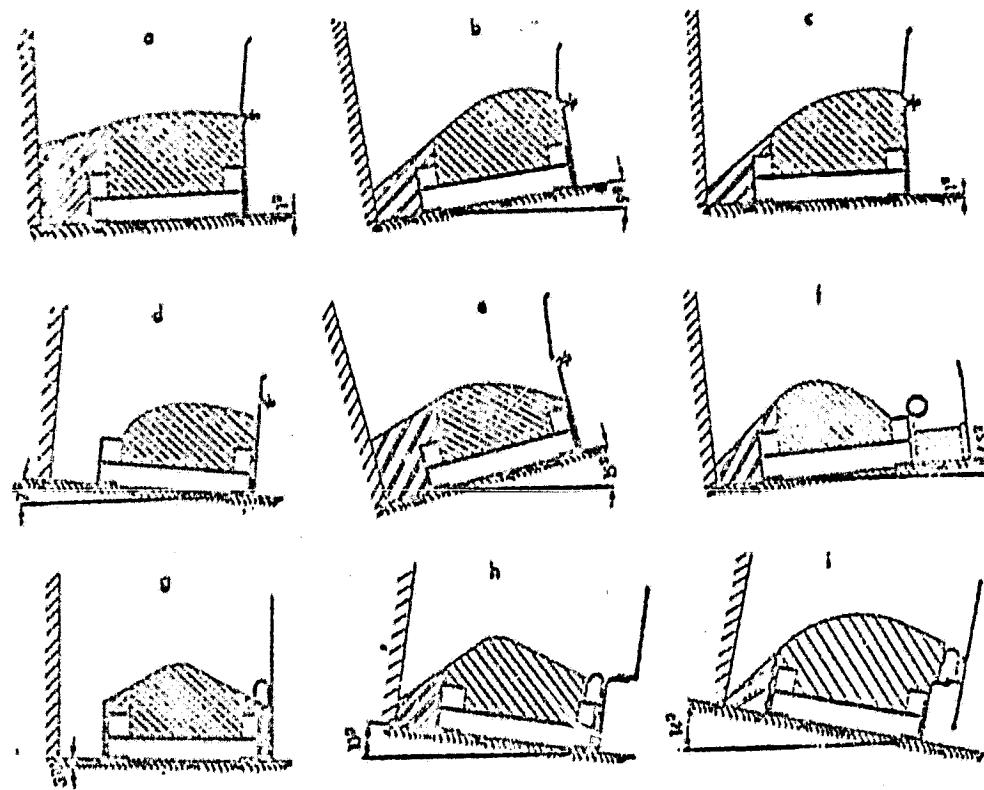


Fig. 15: Cross-section Shapes of measured Fill Cross-sections
a to e: Gouging operations; f to i: carving operations

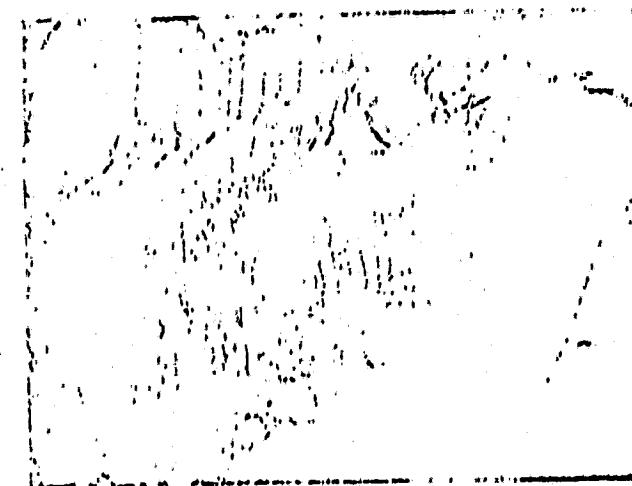


Fig 16: Gouging Lane filled with Conveyed Goods

ness, the design of the mining machine, the width of the mining lane and the conveyor lateral slope. If the conveyor load exceeds the natural goods cross-section then the goods unload in the lane between conveyor and face (fig. 16). Thus a support wall consisting of crushed goods forms which acts like a sheet-metal attachment. In the studied gouging operations the break surface formed between the dropped goods and the moving conveyor flow somewhat perpendicularly above the inside edge of the upper trough guide. On the backfilling side the goods flow moves up to the sheet-metal attachment. /112

The measured fill cross-sections lie on the average 15 to 115% and peaks of 40 to 250% above the theoretical goods cross-sections. The largest measured fill cross-section in a gouging brace conveyor was 2900 cm^2 at a conveyor width of 620 mm (fig. 17) The limit lines of the goods surface could be determined on the studied brace conveyors as curves with more or less steep falling flanks. Equations 10 and 11 to calculate the pressure factors presume flat limit surfaces on the crushed goods. In most cases the goods slope out from the middle of the conveyor at about 30° to the face and at about 15° to the sheet-metal attachment. We were able to determine that for cross-sloped conveyors the sloping angles decrease in the direction of slope. The decrease in angle of friction can be calculated according to G. Pajer and F. Kurth [21] as a function of the slope of the support. In the calculations of characteristic line fields for the sake of simplicity we subtracted an angle of 5° from the normal sloping angles.

Both for practical application of the characteristic lines and for scientific comparisons it is advantageous to prepare $c_{\mu\mu}$ V-curves for the constant fill cross-section. Thus the load levels must be determined first for a calculation of the wall friction. With the dimensions of the conveyor (fig. 18) and under consideration of the slope there result the levels for the selected fill cross-sections at the face side of the conveyor as:

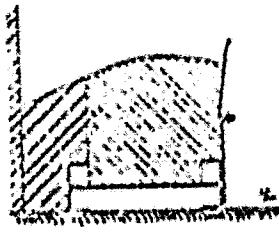


Fig. 17 Measured Fill Cross-section in a Gouging Brace Conveyor
(See fig 12 for explanation of symbols)

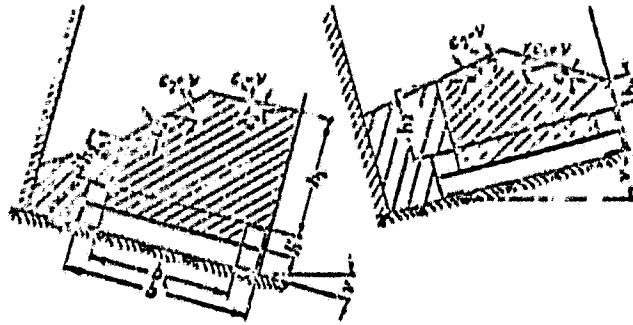


Fig. 18 Approximated fill Cross-section Shapes for Cross-sloped Conveyors

$$h_2 = \frac{2F - 2b_1 h' - \left(\frac{b_1^2}{4} + \frac{b_1 b_2}{2} \right) \tan(\epsilon_2 \pm \nu) + \frac{b_2^2}{4} \tan(\epsilon_1 \mp \nu)}{b + b_1} \quad [17]$$

and on the backfilling side of the conveyor we have:

$$h_1 = h_2 + \frac{b_1}{2} \tan(\epsilon_2 \pm \nu) - \frac{b_2}{2} \tan(\epsilon_1 \mp \nu) \quad [18]$$

Substitute into the equations for:

Conveyor sloped to the backfilling (suspended)

$$(\epsilon_1 - \nu); (\epsilon_2 + \nu)$$

Conveyor sloped to the face (declining)

$$(\epsilon_1 + \nu); (\epsilon_2 - \nu)$$

As specific characteristic line equation for raw coal conveyance we have the following equation for conveyor speed > 0.1 m/s with reference to eq. 14, 15, 16:

$$c_s = \frac{q_K (0.28 - 0.0375 \nu) + (q_0 + \frac{h_1^2}{2} \lambda_a \gamma) (0.39 - 0.00625 \nu) + \frac{h_2^2}{2} \lambda_a \gamma \mu_i}{q_K + q_0} \quad [19]$$

The break-loose points were also calculated by this equation with the adhesion friction values $\mu_K = 0.3$; $\mu_0 = 0.43$; $\mu_i = 0.86$. The internal friction of the crushed goods which must be surmounted at the break surface of the face was substituted as a constant $\mu_i = 0.86$ [20] into the calculations.

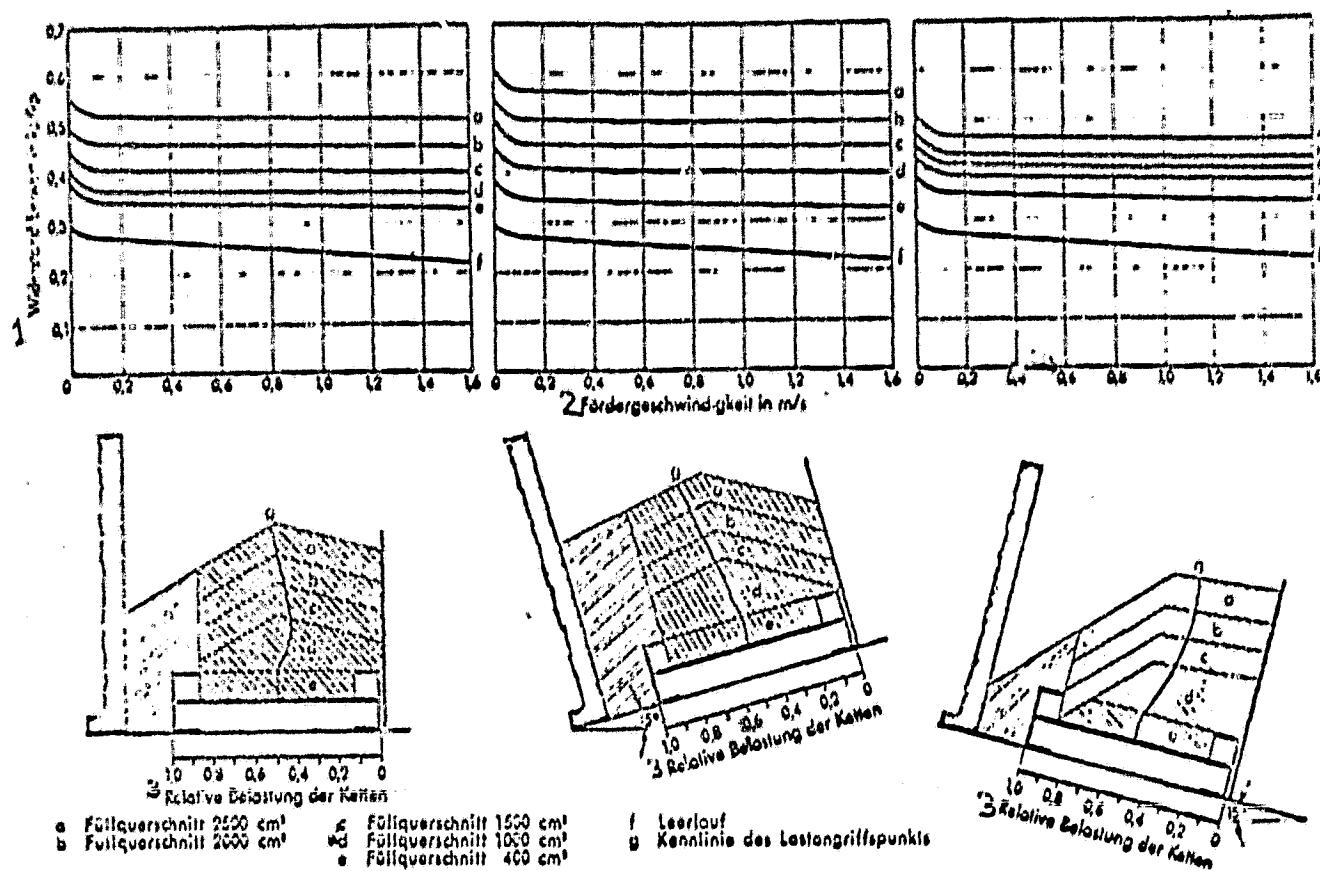


Fig 19: Characteristic Lines of the Upper End-piece of a Brace Conveyor of 620 mm width at the illustrated Cross-slope, fill cross-section and fill cross-section size. Key: 1-coefficient of resistance in kp/kp 2-conveyor speed m/s 3-relative load of the chain a-fill cross-section 2500 cm² b-fill cross-section 2000 cm³ c-fill cross section 1500 cm² d-fill cross-section 1000 cm² e-fill cross-section 400 cm² f-idle g-characteristic line of the load attack point

Resistance Characteristic Line Fields and Characteristic Lines of the Load Attack Point

The calculated line fields are shown in fig. 19. For a brace conveyor with a design width of 620 mm and a cross-slope of 0° the coefficient of resistance will increase at a speed of 0.8 m/s from the base load ($F_5 = 400 \text{ cm}^2$) from 0.33 (100%) to 0.46 (140%) at a fill cross-section of $F_4 = 2000 \text{ cm}^2$; it increases to 0.52 (158%) at $F_5 = 2500 \text{ cm}^2$. The last cross-section is not excessively large. For the same conveyed quantity we were able to measure a fill cross-section of

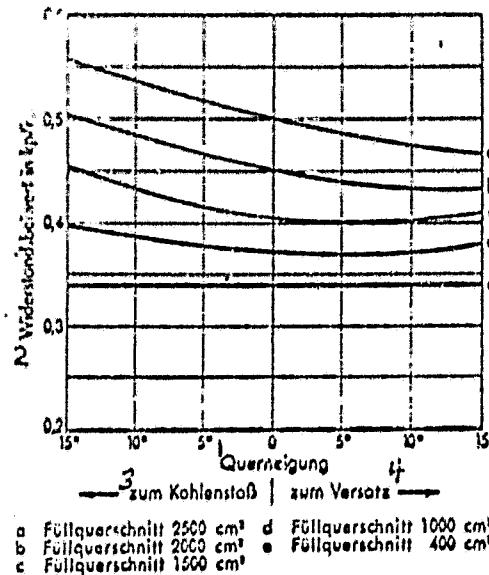


Fig 20: Coefficient of Resistance as a Function of the Cross-slope of Brace Conveyors of 620 mm width for different fill cross-sections

Key: 1-cross-slope 2-coefficient of resistance in kp/kp 3-to the face
 4-to the backfilling a-fill cross-section 2500 cm^2 b-fill cross section 2000 cm^2 c-fill cross-section 1500 cm^2 d-fill cross-section 1000 cm^2
 e-fill cross section 400 cm^2

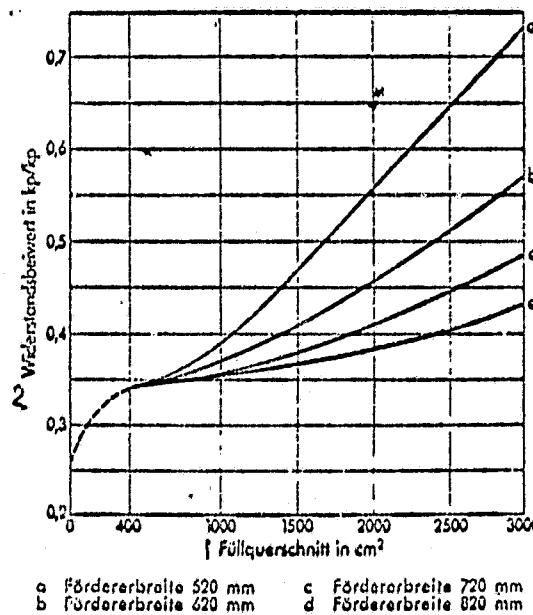


Fig 21 Coefficient of Resistance as a function of the fill cross-section of Brace conveyors for different conveyance Widths

Key: 1 fill cross-section in cm^2 2-coefficient of resistance in kp/kp
 a-conveyor width 520mm b-conveyor width 620 mm c-conveyor width 720 mm
 d-conveyor width 820 mm

$F = 2900 \text{ cm}^2$ in a gouging brace conveyor (fig 17). Conveyor cross-slopes inclined to the face--i.e. descending face advance--cause a notable increase in coefficients of resistance due to the large friction surface at the goods.

Figure 20 shows the coefficients of resistance as a function of the conveyor cross-slope for various fill cross-sections. /114

The illustrated results are of significance for projections of brace conveyors for high-performance operations. A 620 mm wide brace conveyor is able to master flows of cross-section up to 3000 cm^2 due to the predominate drag mode of operation. According to fig. 21 a coefficient of resistance of 0.57 occurs. For the same size cross-section the resistance is reduced to 0.43 for an 820 mm wide conveyor. Selection of the larger conveyor would be connected with a reduction in chain forces and drive power by 25% in this case.

Due to the numerous fill cross-section shapes, the cross-slope of the conveyor and the wall friction resistances at the sheet-metal attachments and at the standing crushed goods in the mining lane, we expect an unequal load distribution in the brace conveyor. The asymmetric position of the load attack point results in double-chain conveyors of different chain loads. The characteristic lines of the load attack point plotted against the conveyor width (fig 19) provide information about the percentage load on the chain. In extraction operations with falling or suspended face advance the load distribution should receive special attention. For suspended face advance $<15^\circ$ there results a load pick-up of 65% of the total chain load for $F_4 = 2000 \text{ cm}^2$ for the chain on the backfilling side.

Characteristic Conveyor Lines

The proven measurement method for pointing up the characteristic conveyor lines was expanded with the objective of future operating measurements which are needed in particular for the measurement of lower end-piece resistance. From the viewpoint of drive, the characteristic conveyor line is superior to the resistance line. The characteristic conveyor line represents the actual load line of the working conveyor. In the form of the function $c_F = f(v)$ the specific force c_F contains the force demand to meet the chain drive losses, in addition to the end-piece resistances.

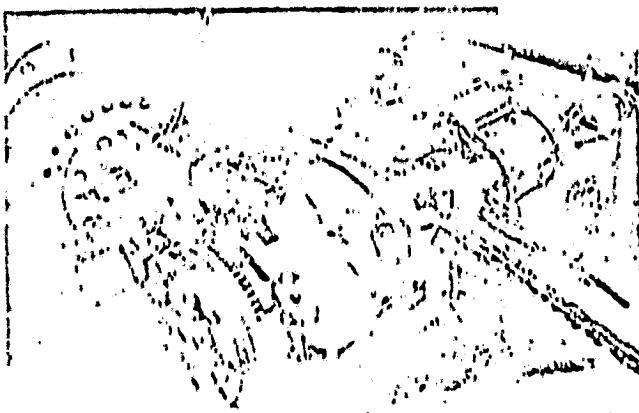


Fig. 22: Drive of the Test Conveyor with Torque-Speed Pick-off at the Transmission Shear Head. Chain force pick-off behind the chain wheel.

As test conveyor we used a single-chain conveyor with head drive (fig. 22). A special torque-speed pick-off permitted recording of the specific drive force as a function of the conveyor rate in connection with the analog computer. A chain force pick-off served to measure the chain prestress parameter. The measured values were transmitted wireless. The torque pick-off was located in the shear head of the transmission. Instead of the shear bolt, a pressure pin with strain quage was located tangentially in the force flux between the outside and inside shear face. The effective circumferential force, multiplied by half the travel diameter of the measurement bolt, gives the torque. The advantage of this torque measurement unit consists in the fact that it takes up very little space and that it can be calibrated quite accurately with little difficulty. The tests were limited to the conveyor idle speed. They served primarily to check the developed transducers and to point up problems with the chain scraper conveyors which would need additional research work. The characteristic conveyor lines were taken with optimum chain prestress and with larger prestresses (fig. 23).

Large chain prestresses have an extremely disadvantageous effect on the line profile and on the size of the specific power consumption. The conveyor lines rise (in contrast to the resistance lines) with the speed and this effect

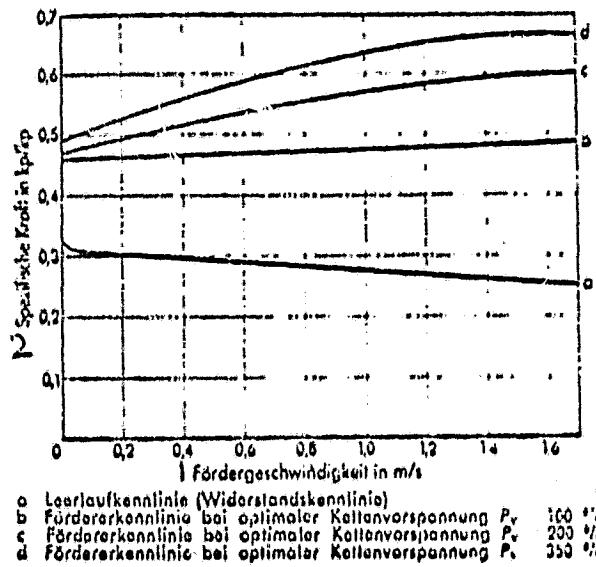


Figure 23. Characteristic Conveyor Lines for various Chain Prestresses at Conveyor Idle.

Key: 1-conveyor speed in m/s 2-specific power in kp/kp a-idle line (resistance line) b-conveyor line at optimum chain prestress $P_v = 100\%$ c-conveyor line at optimum chain prestress $P_v = 200\%$ d-conveyor line at optimum chain prestress $P_v = 350\%$

is more pronounced the greater the chain prestress. The difference in specific forces is represented by the chain gear losses of the drive and reversal.

A generalization of the obtained measured results is not permissible since on the one hand the chain loads at idle are too small and since the chain drive losses appear to depend very much on the design of the chain wheels. Thus special chain drive studies shall be performed with the objective of creating the background for the design of chain wheels which will ensure a minimum of power losses from chain and chain wheel wear. The results of another test series also indicate the need for chain drive studies. For a complete revolution of the chain force pick-off the chain force and torque were measured and plotted as a function of time (fig. 24). As the upper measurement strip of fig. 24 shows, the chain was provided with optimum prestress since the prestress force goes to zero after start-up. The larger ascent of the first section of the curve is attributable to greater coefficients of friction in the lower end-piece. The reversal station caused the jump about in the middle of the tensile force curve. The jump level is a measure for the losses in the

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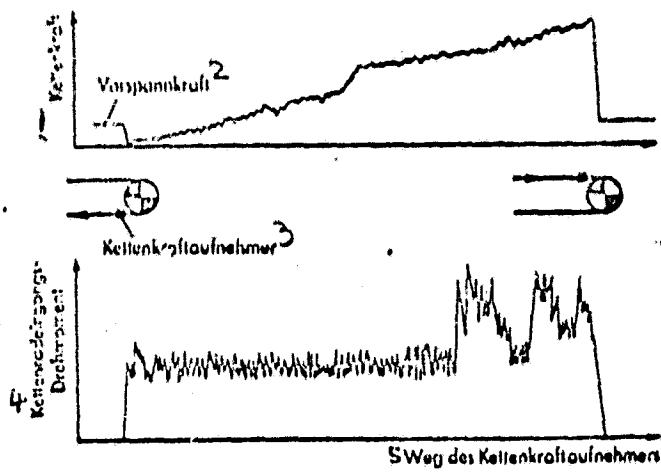


Fig. 24: Qualitative Chain Force and Torque Profile. Copies of original Plots. Key: 1-Chain force 2-prestress force 3-chain force pick-off 4-chain wheel initial torque 5-path of chain force pick-off

reversal. In the last section of chain circulation the torque increases quickly. The larger torque value is due to increased chain drive losses since an increase in chain forces plotted synchronously with the torque did not occur. In the region of large torque the chain links has an approximately 2% greater spacing.

Summary

In view of the numerous operating conditions to which the portable chain scraper conveyor is exposed in pit operations, reliable calculation principles can only be created through research on individual resistances and losses.

In a special test stand the basic behavior of mining crushed goods in chain scraper conveyors was explained. The characteristic resistance lines of the upper end-piece were determined for conveyor idle and as a function of the determinative crushed goods characteristics, on the size of the conveyor load, on the conveyor construction and on the stopped time of the conveyor. Crushed goods with a narrow granular profile and sphere-like grains caused about 35%

greater resistances than fine coal and raw coal with broad granular profile due to the severe relative motions of the goods on the conveyor. For water-containing goods $>10\%$ by weight the solids friction retreated in favor of flow friction. The coefficients of resistance decreased considerably in the range of lower speeds and then increased with increasing conveyor speed.

The grinding resistance in the conveyor increases with the density of the goods. The conveyance of sandstone ore required about 280% greater specific drive energy than the conveyance of raw coal. Resistance coefficients for coal and raw coal showed no dependance on the design of the conveyor.

Start-up of loaded conveyors after longer stop times was simulated. The specific break-loose force increases for crude coal after a stop time of 68 h by 72% over the break loose force of normal operation with short-term stoppages. The coefficients of resistance increase with the conveyor load. This behavior could be explained by the laws of soil mechanics. Equations permit calculation of fields for characteristic lines of resistance as a function of the fill cross-section size and shape, of the conveyor size and of conveyor employment conditions. Characteristic lines of the load attack point provide information on the distribution of chain forces in the conveyor end-piece. By means of a developed torque-speed pick-off which is housed in the shear head of conveyor transmissions, we were able to obtain plots of characteristic conveyor lines whose profiles show a strong dependance on the chain prestress. Between the chain drive losses and the condition of the conveyor chain and chain wheels we were able to find a sensitive relationship.

Appendix

Symbols Used

Numerical Value	Quantity	Unit
a	Conveyor angle of slope	
c_F	Specific drive force	
c_u	coefficient of resistance of the upper end-piece	kp/kp
c_n	Coefficient of resistance of the lower end-piece	kp/kp

Numerical value	Quantity	Unit
F	Fill cross-section	m^2
η_A	Efficiency of the drive	
η_K	Efficiency of the chain drive	kp/m^3
γ	Crushed goods weight	m
H	Lift height	m
h, h_1, h_2	Support wall height	m
k_1	Factor of supplemental resistance	
k_2	Wall friction resistances	m
l	Axis distance	
$\lambda_1, \lambda_2, \lambda_3$	Pressure factors	
μ	Coefficient of Friction	
μ_0	Average coefficient of friction	
μ_1	Adhesion value	
μ_2	Friction value of the conveyed goods on conveyor	
μ_3	Friction coefficient of internal friction of conveyed goods	
μ_4	Idle friction value	
μ'_K	Average friction value of conveyed goods	kW
N_{IIa}	Average idle friction value	kW
N_{III}	Engine power at main drive	
ψ	Engine power at auxiliary drive	
φ_0	Factor for conveyor curves	kp/m
q_K	Meter-weight-force of conveyed goods	kp/m
v	Meter-weight-force of conveyor chain	m/s
b	Conveyor speed	mm
l_M	Width of conveyor	m
l_B	Length of measurement range	m
b_1	Length of load range	mm
d	Distance between the two conveyor chains	
a	Ascent of straight section of curve in fig. 13	

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